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Hall probe bench prototype for closed magnetic structures

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Abstract

In house characterization of long and narrow closed magnetic structures becomes a challenging need due to the difficult accessibility to the structure, such as a vacuum chamber or the magnet yoke itself. In addition, considering the case of an in vacuum insertion device, the free space to move the hall probe along the magnetic array is very narrow being around 5 mm height and 25 mm width creating a tight space in order to locate the hall sensor and its supports. To solve those difficulties a new design is proposed by out craning the hall probe sensor in order to locate it in the middle of the magnetic structure and move and position it for the measurement by a high stability XYZ table, which will perform with accuracies of 20 microns and resolutions of better than 1 micron. Repeatability specifications are also very tight and for that all the movement axis have to be encoded. Roll angle accuracy of the hall sensor is very critical and because of the out craning of the support, will determine important constrains on the design. Eigen modes of the whole system have been estimated in order to be in a safety range to skip the excitation of environmental vibrations sources. For all that reasons, the positioner has been designed accordingly, using design criteria of high accuracy mechanics. The structure that allows the hall sensor to pass through the magnetic array needs to be mounted before the measurement but the vacuum chamber doesn't need to be disassembled. For that, the closed magnetic structure can be characterized under final conditions. In addition, this bench can measure all open structures being characterized up to now with conventional hall sensor benches, covering all the possible scope of magnetic measurements.

Keywords**:** Hall probe bench, closed magnetic structures, insertion device magnetic characterization

1 INTRODUCTION

ALBA has set up complete magnetic measurements laboratory specialized in characterization of big magnetic structures used in accelerators physics and technology. Devices like 3m long Hall probe bench, Fixed stretched wire, Flipping coil and rotating coil are performing measurements from the very beginning of the ALBA project. The need of measuring closed magnetic structures like the in vacuum undulator or the superconducting wiggler was an important requirement because this allows those particular structures to be characterized after being mounted. In this report a new concept of magnetic measurement bench is proposed not only for closed magnetic structures, also for open structures like all current hall probe benches.

The concept proposed is based on a floating arc structure with a tensioned strip where the hall sensor is fixed on the middle. All this assembly is displaced and positioned on the three axes under positioning performances specified.

A small prototype bench with 1200 mm of measuring range has been developed and it's under commissioning, the aim of this development is to learn empirically about this concept in order to construct a bigger bench of 3000 mm range.

2 SCIENTIFIC CASE AND SPECIFICATIONS

The opportunity of performing characterization of a closed magnetic structure under construction appears for the ALBA magnetic measurement laboratory. For that, this first prototype will be specified dimensionally to cover the needs of this particular measurement, which is a magnetic structure with a diameter of around 800 mm.

Specifications will be listed at this point, and they are related to the ranges and position performance of the hall sensor, but before starting the development of the project, a design with a full range of 3000 mm has to be validated

Table. 1. Specifications for the hall sensor movement and performance

Ranges	
X range (*L*)	±125 mm
Z range	±50 mm
Y range	±600 mm
Chamber allowance (*W*)	600 mm from axis
Positioning accuracy in all range	
Δx, Δy, Δz	< 0.05 mm
ROLL Δα, PITCH Δß	< 0.05 mrad
YAW ΔΦ	< 0.10 mrad
Repeatability of movements	
Y, Z, X axis	1 μm
Resolution of movements	
Y, Z, X axis	1 μm
Speed	
Y axis	~15 mm/s

3 CONCEPTUAL DESIGN & DEVELOPMENT

3.1 Draft of the concept

At fig 1 are shown the first dimensioning parameters of the C structure design with the hall sensor in the middle. The dashed line represents the structure of a certain length to be measured, in which the hall sensor has to cover its full measuring range (*L*). The total dimension of the arc and the total dimension of the bench depend on the closed structure length (*L*) which is the measuring range at the same time.

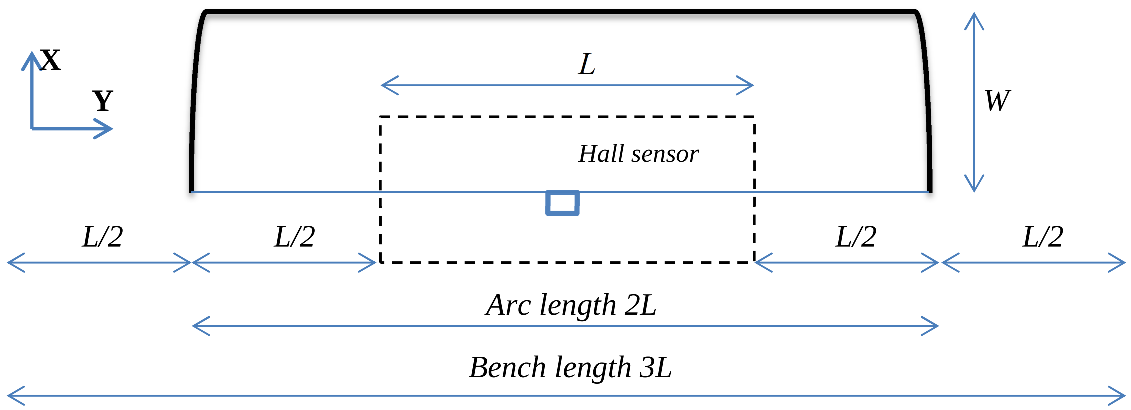


Fig 1. Draft of the concept

3.2 Viability study

The design is based on a strip tensioned by a structure. The viability will consists on determine a range of tensioning forces which keep first vibration modes of the strip in a safe range away from environmental frequencies, considered below 40 Hz. The tensioning force has to be enough in order to maintain the first mode above this frequencies (considering above 40 Hz as a safe range) and the structure must be dimensioned to support this force. Those stability requirements of the design are mandatory to accomplish the specifications.

First vibration modes of a single strip have to be evaluated on different iterations. They have been calculated analytically, and by FEA giving a result which is almost the same. It is concluded that the first mode of vibration of the strip under tension can be calculated with the use of Brook Taylor's equation (1).

Analytical calculations using Taylor's formula, which relates tension (*T*) and fundamental frequency (*f*). This depends on the density of the material (*d*) and the section of the strip (*A*)

$$f = \frac{\sqrt{\frac{T}{d * A}}}{2 * L} \tag{1}$$

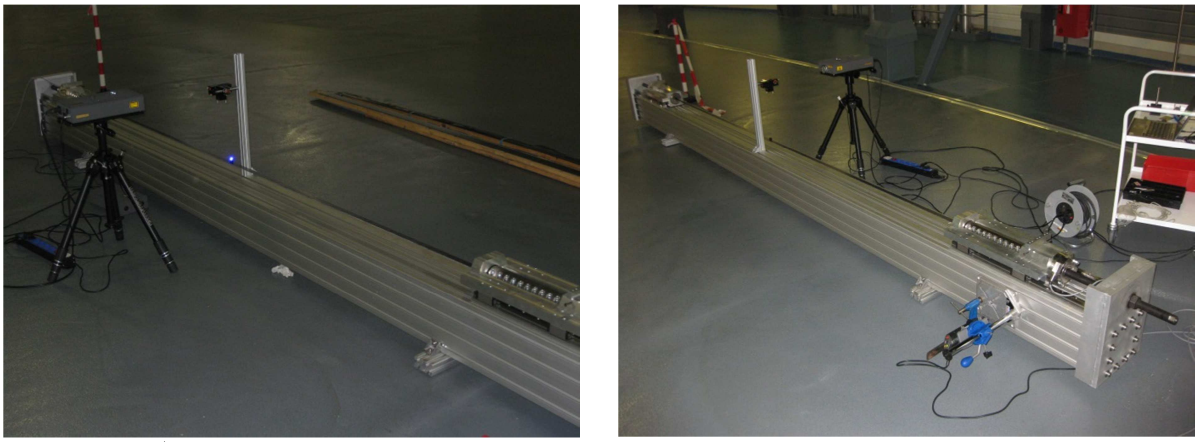
Considering the validation of a full 3000 mm range model, with a carbon fiber strip with a reasonable width to hold the hall sensor (22x1) mm the result obtained is shown on table 2

Table. 2. Viability result

L (m)	*A* (mm^2)	*d·A* (Kg/m)	*T* (N)	σ (MPa) N/mm2	f (Hz)
6	22x1	0.0352	10000	454.6	44.4

An empiric exercise has been performed in order to check the amplitude and roll of a tensioned strip of 24x1,4 mm^2 and 4000 mm under a tension of 8 kN with a shock excitation (fig 2a) or induced constant excitation (see fig 2b). The amplitude and fundamental frequency under a shock are shown (fig

3) and under constant excitation (fig 4) where maximum vibration amplitude is observed when the excitation force increases



a) b)

Fig 2. Measuring setup. The photo on the right shows how the shaker is attached on it.

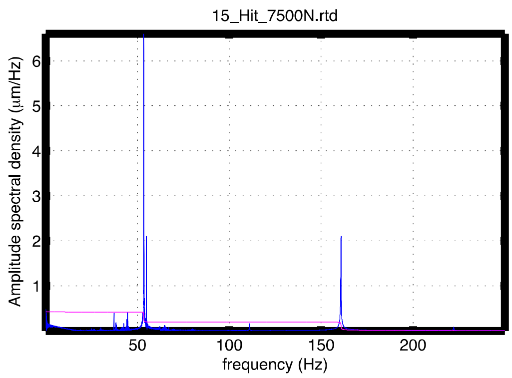


Fig 3. First mode at 50 Hz

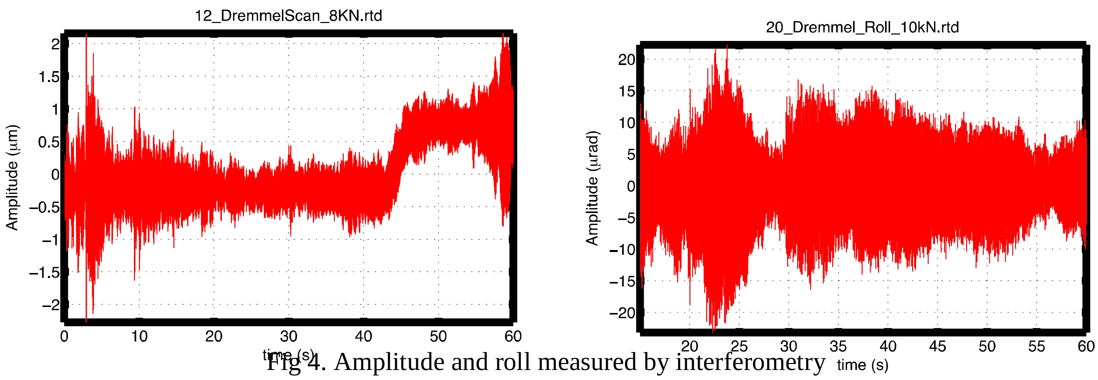


Fig 4. Amplitude and roll measured by interferometry

It is concluded that with a reasonable tensioning force, a strip of around 20 mm^2 can be tensioned up to a fundamental frequency of at least 40 Hz. For lower section of the strip, the highest σ and fundamental frequency, for the same tensioning force. It is concluded that using equation (1) a good compromise can be found for a full measuring range design.

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3.3 Materialization and chosen solutions

The measuring range for the hall probe bench prototype is 1200 mm, a unidirectional carbon fiber strip of 2600 mm will be considered in order to leave a safe margin on the design. According to the dimensions of the XYZ hall sensor PCB, the section of that strip will be 16x1.4 mm2.An arc structure has to be designed with a stretching system that can generate up to 10kN of force, (See fig 5a). A load gauge is integrated on the stretching system (fig 5b)

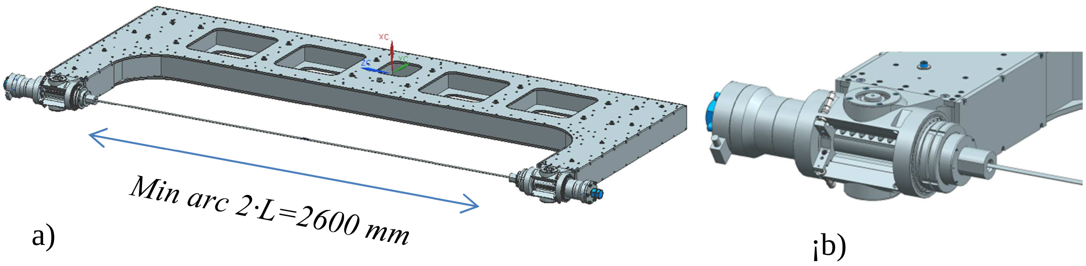

Fig 5. Arc structure and stretching system

To accomplish the specifications on resolution and stability, the arc structure has to be mounted on a XYZ high stability positioner. Z positioner is based on a big granite structure where the arc is mounted on the top by a double flexure system, which will allow the arc structure to move on vertical Z direction and to orient it in yaw (Φ). Each flexure is actuated independently to change the angle or in coordination if height varices. Both flexures are guided with linear guides and movement transmitting is made by motorized spindles. This concept of positioning has been proven at ALBA in many occasions where high stability positioning is required (see fig 6a). The C structure is attached on the top of this positioner (fig 6b)

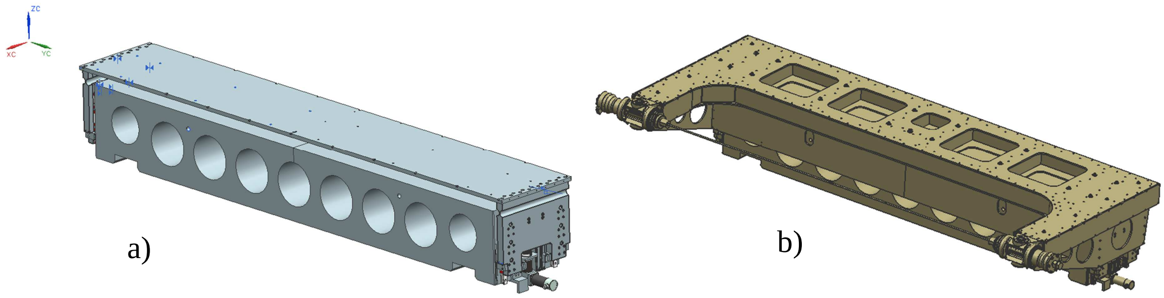

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Fig 6. Z positioning system

All the structure shown at fig 6b is mounted on a XY positioner (see fig 7) based on a huge granite block, guiding systems and motorized spindles. High accuracy mechanics criteria’s are followed in order to reach the specs in accuracy and resolution. All movements of the high stability XYZ are encoded in order to guarantee the repeatability on the positioner, but not in the hall sensor. The Y movement spindle has to be oversized to increase the first mode of vibration of the complete system which can be low due to the big mass pushing on it.

Due to the morphology of the system, the X moving system has been done by two actuators separated in order to increase the rigidity on the assembly. Otherwise, the system will be very weak in rotation along Z axis. To avoid overstresses on the assembly, each X spindle position has been encoded separately. Rigid guiding is guaranteed for each actuator.

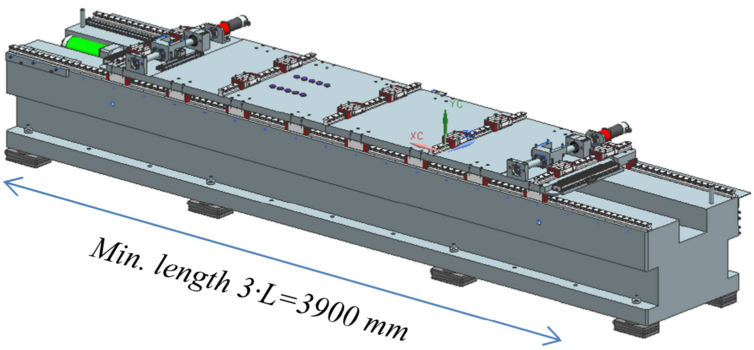
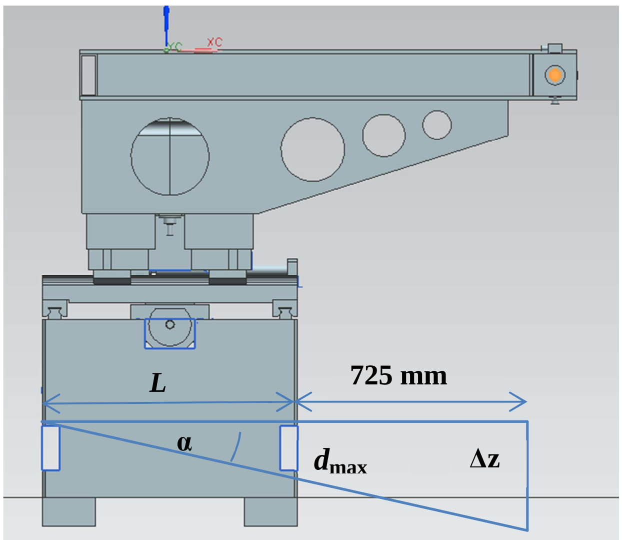


Fig 7 XY positioning system

Roll angle and Z deviations of the hall sensor are very critical due to the out craning of the system, which is imposed by the chamber allowance and the X range (see table 1). Roll and Z deviations will define an strict budget tolerance on the vertical accuracy of the linear guides and its separation (see fig 8).: The maximum deviation between height of the linear guides (d_{max}), will impose a roll angle α to the hall sensor. This error will be amplified due to the lever arm to the Z deviation. Linear guide separation (L) has to be dimensioned according to that budget (see eq 2), as the planarity of the granite top surface. A matched pair of linear guide set has been considered to minimize the value of d_{max}.



$$\frac{dmax}{L} = \frac{\Delta z}{L+725} \qquad (2)$$

3.4 FEA analysis

The model has been evaluated considering a tension on the arc of 10 kN, where a maximum tension of 57 MPa (see fig 9a) is located on the aluminum arc. First mode of vibration at 32 Hz (see fig 8b) corresponds to the movement of the big Z stage due to its mass and the weakness of the spindle in the direction of the movement. The design has to be lightened as possible for that stage without losing rigidity Second mode is at 42 Hz (fig 8c). The flexure system for the Z stage has been evaluated for an extreme case where both flexures are separated 11 mm in height, which correspond to an inclination of 0.2º. The stress is located in the flexure, of about 135 MPa, and for that high modulus steel is required. The model it's evaluated on one of the extreme positions and its shown that the maximum deformation is due to the tensioning force of the stretching system.

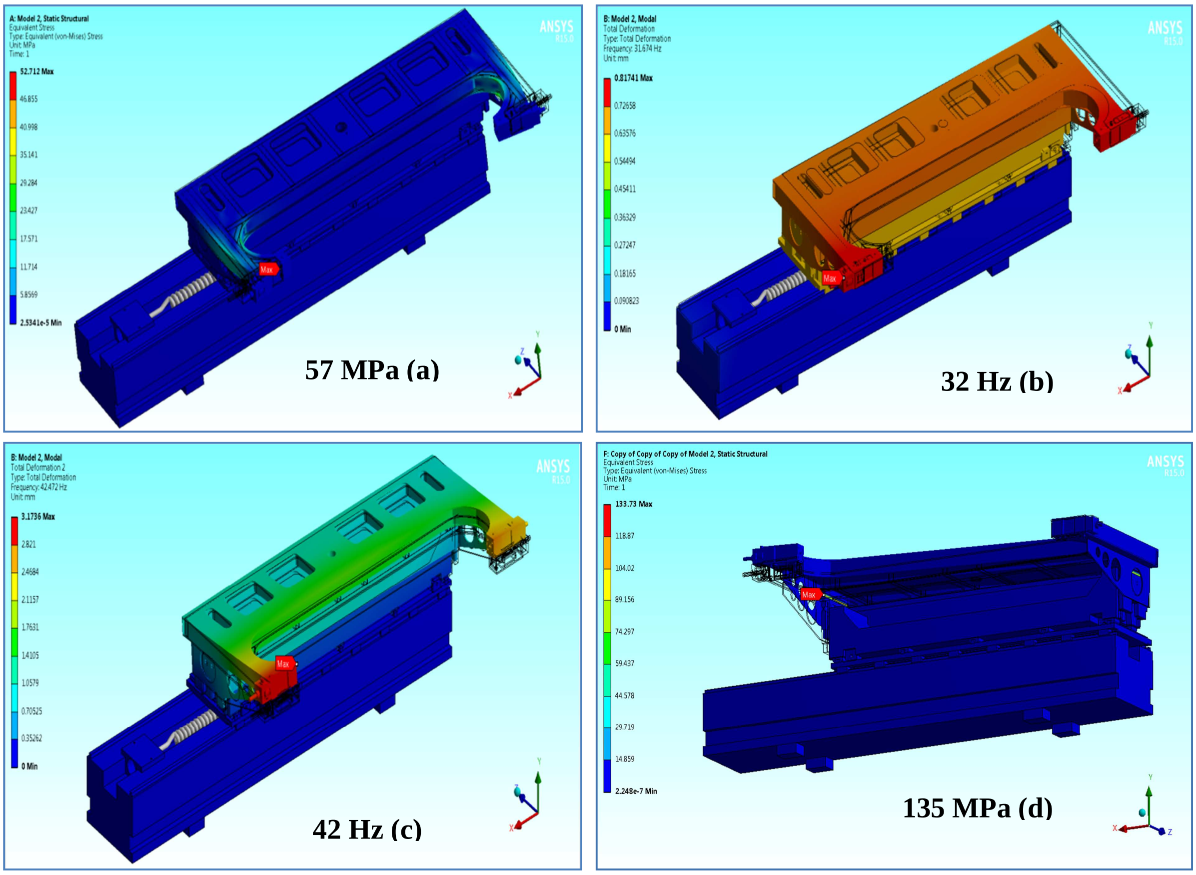


Fig 9 element analysis FEA

4 PRODUCTION AND MOUNTING

The production of the bigger pieces has been outsourced to external workshops due to size capabilities or planarity requirements. Granite blocks have been outsourced to external companies, the rest of the pieces have been manufactured at CELLS workshop. Assembling of the device has been done on the experimental area, with the help of the alignment group on each of the stages of the assembling.

First of all the XY granite has been aligned flat in respect to the absolute horizontal plane sitting on the top of 8 *airlocks*: One of the long linear guides is aligned horizontally. Survey and alignment procedures using a laser tracker are repeated on each stage of the mounting in order to insure the leveling of each component and the accurate parallelism of each of the transversal and vertical linear guides. On the next picture (fig 10) it is shown the complete assembly before evaluation.

Fig 10 XYZ Assembled hall probe bench,. Ready for measurements

5 FIRST MEASUREMENTS

5.1 Guidance error for XYZ axis

HA measurement set up with a laser tracker has been prepared putting the iris on the top of the strip (see fig 11). This was previously tensioned up to 600 N and moved in the XYZ axis. The set up gave us the following results in a precision of about 20 µm, For the longitudinal axis can be seen on fig 12, for the vertical (Z) and transversal (X) axis the guidance errors obtained are of the same range

Fig 11 XYZ different setups used for measurement Laser tracker iris and interferometer for pitch and yaw

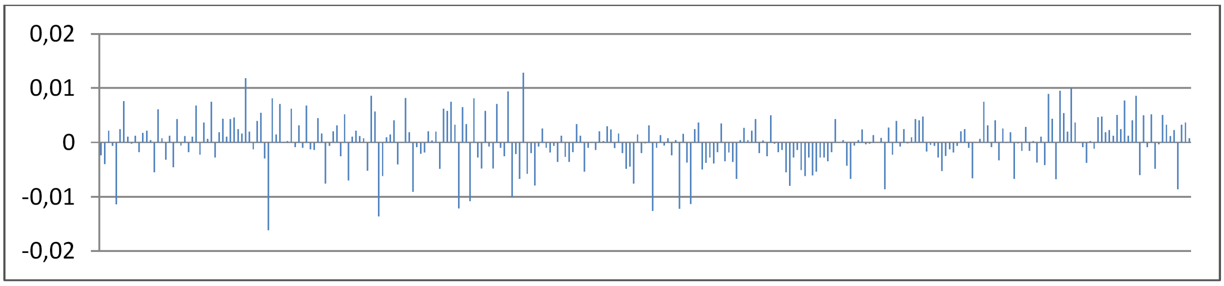


Fig 12. Guidance error on the Y axis (1200 mm range)

5.2 Roll pitch and yaw

Angular errors have been measured with a setup prepared by an interferometer. As a first approach, a mirror has been attached on the top of the fiber and the angle evolution is measured when moving. The results for several scans are shown on the next picture

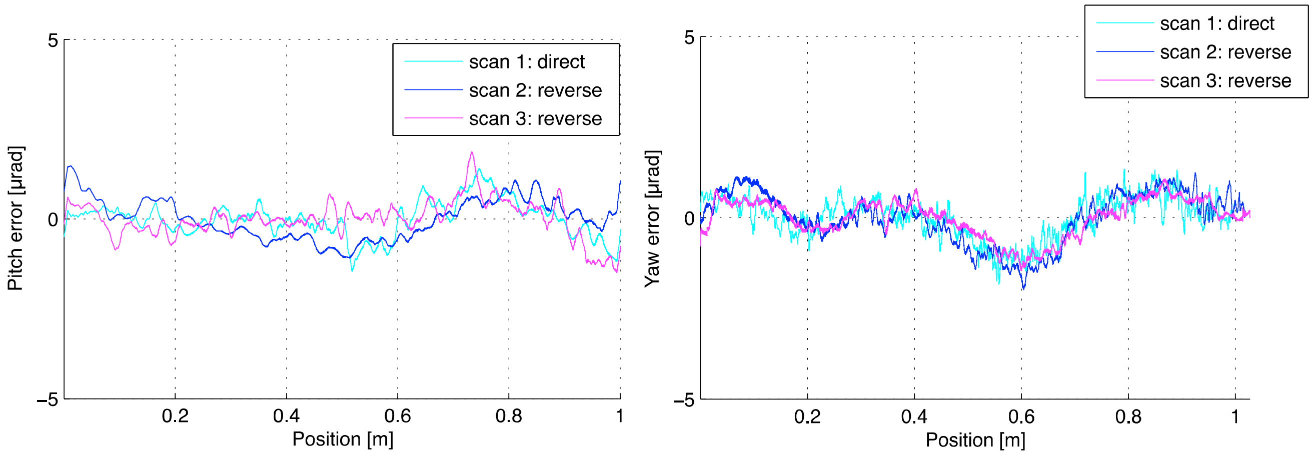
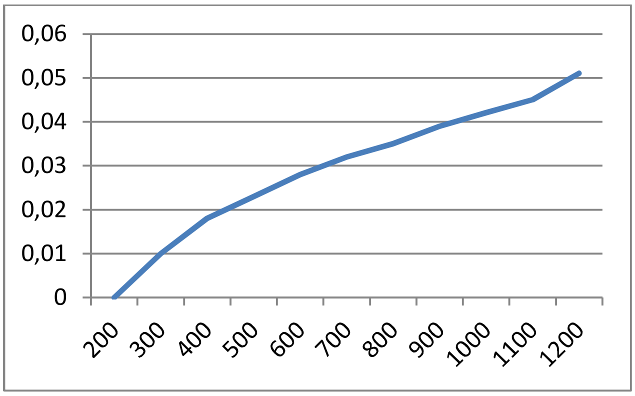


Fig 13. Pitch and Yaw measurements

The roll evolution has been measured with a set up based on an electronic level, which is fixed on the top of the C structure, taking in consideration that the carbon fiber strip is solidary to the C structure and both are moving together. The result obtained is 50 mrad for the full range which is at the limit of the specification (see fig 14)



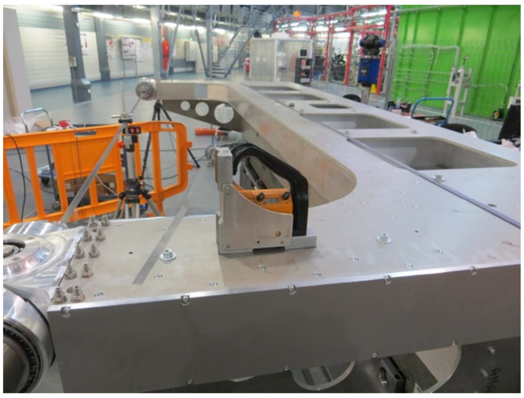


Fig 14. Roll angle deviation. Set up used is shown at the right photo

5.3 Vibration tests

A setup with accelerometers has been prepared. The positions chosen were at the top of the C structure, the floor and one for each stretching gauge. The vibration spectrum has been obtained in static and in longitudinal movement (Y scan). For the last one, which is presented at fig 15, shows the modes previously calculated by FEA at 35Hz and 45 Hz, and a main mode coming from the ground (50 Hz). Few other types of amplitude observed are coming from the excitation of the motors.

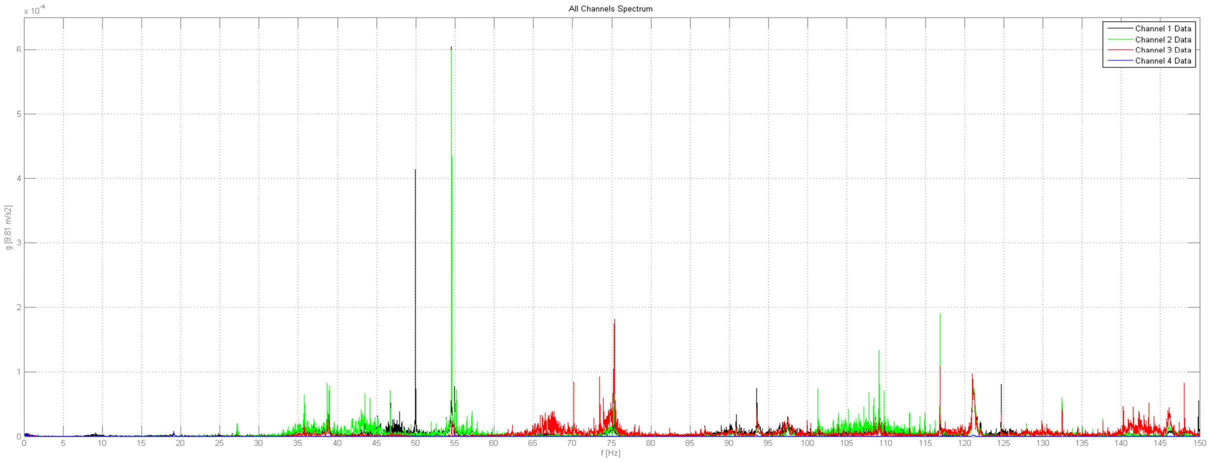


Fig 15. Vibration spectrum for Y scan

6 CONCLUSIONS

After validating a theoretical model and obtaining the expected results from that design, This solution can be extrapolated for a longer range of 3000 mm in order to measure long and narrow closed magnetic structures such an in vacuum undulator and superconducting wiggler. .

The specifications requested can be guaranteed, as by design, the guidance error of the linear guide has been translated on the position of the hall sensor. Otherwise, more detailed measurements have to be done by interferometry in order to certificate the prototype on the precision level of an optical measurement, and get values for the real resolution and repeatability on the three axis.

This short 1200 mm range prototype is valid for measuring closed magnetic structures, but can be used also for conventional open magnets with a narrow gap between poles.